MINIMAL EFFECT OF ACUTE CAFFEINE INGESTION ON INTENSE RESISTANCE TRAINING PERFORMANCE

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ABSTRACT

Astorino, TA, Martin, BJ, Schachtsiek, L, Wong, K, and Ng, K. Minimal effect of acute caffeine ingestion on intense resistance training performance. J Strength Cond Res 25(X): 000–000, 2011—The primary aim of the study was to determine the efficacy of acute caffeine intake to enhance intense resistance training performance. Fourteen resistance-trained men (age and body mass = 23.1 ± 1.1 years and 83.4 ± 13.2 kg, respectively) who regularly consumed caffeine ingested caffeine (6 mg·kg⁻¹) or placebo 1 hour before completion of 4 sets of barbell bench press, leg press, bilateral row, and barbell shoulder press to fatigue at 70–80% 1-repetition maximum. Two minutes of rest was allotted between sets. Saliva samples were obtained to assess caffeine concentration. The number of repetitions completed per set and total weight lifted were recorded as indices of performance. Two-way analysis of variance with repeated measures was used to examine differences in performance across treatment and sets. Compared to placebo, there was a small but significant effect (p < 0.05) of acute caffeine intake on repetitions completed for the leg press but not for upper-body exercise (p > 0.05). Total weight lifted across sets was similar (p > 0.05) with caffeine (22,409.5 ± 3,773.2 kg) and placebo (21,185.7 ± 4,655.4 kg). Yet, there were 9 ‘responders’ to caffeine, represented by a meaningful increase in total weight lifted with caffeine vs. placebo. Any ergogenic effect of caffeine on performance of fatiguing, total-body resistance training appears to be of limited practical significance. Additional research is merited to elucidate interindividual differences in caffeine-mediated improvements in performance.

KEY WORDS muscular endurance, fatigue, adenosine, caffeine metabolism, bench press

INTRODUCTION

The ergogenic properties of caffeine have been identified since the early 1900s (29). Early data (8,20) revealed an ergogenic effect of caffeine on endurance performance. Subsequent studies revealed that caffeine enhanced performance during time-to-exhaustion trials (35), prolonged rowing (5), swimming (25), and team-sport performance (32). Nevertheless, there seems to be no effect of caffeine ingestion on peak power (16,17) or repeated sprint performance (27).

However, the ability of caffeine to enhance dynamic muscular strength and endurance has received less attention. In 1 study (23), a 7 mg·kg⁻¹ caffeine dose significantly enhanced muscular strength measured with isokinetic dynamometry, yet no effect of a lower dose (5 mg·kg⁻¹) was revealed in another study (4). Only a few studies have examined the effect of caffeine on dynamic resistance training performance. Compared to placebo, greater 1 repetition maximum (1RM) bench press was demonstrated in resistance-trained men (3) after ingestion of a caffeine-containing supplement, yet no difference in leg press 1RM was evident. In contrast, Jacobs et al. (22) revealed no effect of caffeine (4 mg·kg⁻¹) on muscular endurance. In resistance-trained men (40), 300 mg of caffeine did not affect muscular strength (1RM) or endurance (repetitions to failure at 80% 1RM) compared to placebo. Similarly, no effect of caffeine (6 mg·kg⁻¹) on 1RM bench press or leg press was demonstrated in strength-trained men, although a trend was revealed for enhanced muscular endurance compared to placebo (1). However, the majority of these studies used exercise protocols that do not mimic a typical strength training regimen, and subjects were both users and nonusers of caffeine. Because of the popularity of resistance training and widespread use of caffeine as an ergogenic aid, additional study to examine the effect of caffeine on intense resistance training performance is warranted.

It has been reported (1,24) that there are ‘responders’ and ‘nonresponders’ to the physiological actions of caffeine, likely because of discrepancies in training status or caffeine metabolism across subjects. In untrained men, Bond et al. (4) reported no effect of caffeine ingestion on knee extension and flexion torque; yet using a similar protocol, Jacobson et al. (23) revealed a significant effect of caffeine on muscular...
torque in football players. Bench press performance and Wingate-derived peak power were also significantly enhanced with caffeine intake in elite male athletes (41). It is possible there is an unknown trait of trained muscle that enhances acute responses to caffeine. Alternatively, caffeine metabolism markedly varies across individuals (31). Cornelis et al. (7) demonstrated that a small substitution in the gene regulating caffeine metabolism impairs this process, leading to slowed metabolism, whereas persons homozygous for this allele are ‘rapid’ caffeine metabolizers. Prolonged elevations of caffeine in the body, evident in persons with slow metabolism, may alter performance compared to persons who are rapid metabolizers of caffeine.

The primary aim of this study was to examine the effect of acute caffeine ingestion (6 mg·kg⁻¹) on resistance training performance in strength-trained men who were caffeine consumers. An additional goal was to identify potential ‘responders’ and ‘nonresponders’ through determination of caffeine concentration. This is rarely assessed in studies examining changes in resistance training performance after caffeine ingestion, adding to the novelty of this study. It was hypothesized that compared to placebo, caffeine will not significantly affect resistance training performance.

**METHODS**

**Experimental Approach to the Problem**

Treatment order (6 mg·kg⁻¹ CAF or placebo [PL]) was randomly assigned to subjects. A double-blind, counterbalanced, crossover design was used, as neither investigators nor subjects were aware of treatment assignment. Trials were performed at the same time of the day within subjects and were separated by 1 week to minimize subject fatigue. Subjects initially completed 1RM testing to establish workloads equal to 70–80% 1RM to be used in subsequent testing. They returned to the laboratory 1 week later and completed 4 sets of the following 4 exercises to fatigue: barbell bench press, leg press, lat row, and shoulder press. During testing, the number of repetitions completed and total weight lifted were used to assess performance. Saliva samples were repeatedly obtained to measure caffeine concentration.

**Subjects**

Fourteen resistance-trained men who were daily caffeine consumers participated in the study. They completed total-body resistance training a minimum of 2 d·wk⁻¹ and had been training for 7.5 ± 1.2 years (range = 2.5–18.0 years). They did not take any medications or supplements that alter muscular function. Mean age, height, body mass, and percent body fat (%BF) were equal to 23.1 ± 1.1 years, 1.80 ± 0.02 m, 83.4 ± 3.53 kg, and 13.3 ± 2.8%, respectively. From a 24-hour diet recall, average caffeine intake was equal to 218.2 ± 28.1 mg·d⁻¹, with a range of 120–500 mg·d⁻¹. Subjects filled out a health-history questionnaire and provided written informed consent before participating in the study, and all experimental procedures were approved by the University Institutional Review Board.

**Monitoring of Exercise Status and Dietary Intake**

Subjects completed 24-hour diet and exercise recalls before each trial. They were required to follow the same diet in the 24 hours preceding each trial. Subjects were provided a list of items that contain caffeine, such as coffee, chocolate, soda, energy drinks, and common over-the-counter medications, so they would abstain from caffeine intake for 48 hours previsit. Subjects were also required to complete no intense exercise in the 48 hours preceding each laboratory visit, and ingest nothing other than water in the 3 hours before each trial. Adherence to these requirements was verified with a brief questionnaire administered before each trial.

**Treatment Ingestion**

Anhydrous pharmaceutical-grade caffeine or placebo (dimethyl cellulose) was contained in identical capsules and ingested with water 1 hour pre-exercise. These were prepared by a pharmacist with no involvement in the study. The CAF dose was equal to 6 mg·kg⁻¹, as this has been shown to maximize blood levels of caffeine (15). One week later, subjects ingested the other treatment and repeated the identical exercise protocol at the same time of day.

**Baseline Measurements**

On day 1, subjects’ height, weight, and %BF were assessed. Percent body fat was measured using a sum of 3 skinfold model (21). The primary investigator took all measurements at the abdomen, thigh, and chest following standardized procedures (18). Then, subjects warmed up on a commercial upright stationary bike (Precor C842, Woodinville, WA, USA) for 5 minutes, followed by a warm-up set of 12–15 repetitions on the flat barbell bench press at a load equal to 45–60 kg. Determination of 1RM for barbell bench press, seated 45° leg press, bilateral row, and barbell shoulder press was completed on free weight equipment (Cybex, Medway, MA, USA) according to standard methods (2). Two minutes of rest was allotted between sets, and 1RM was determined in 3–5 sets. 1RM represented the maximum weight lifted once with proper form. Subjects were given verbal encouragement throughout the protocol. In strength-trained men, pilot testing revealed no difference in 1RM bench press (t = 1.73, p = 0.23), leg press (t = −0.46, p = 0.69), bilateral row (t = 0.37, p = 0.57), or shoulder press (t = 0.89, p = 0.33) measured over 2 days, with a coefficient of variation in 1RM equal to 4.5, 4.7, 4.0, and 4.1% for each exercise, respectively.

**Exercise Protocol**

After refraining from caffeine and intense exercise during the previous 48 hours, subjects returned 1 week later at the same time of day. They ingested the capsule and sat down in a chair in a quiet, climate-controlled environment (21–23°C, 40–50% relative humidity) for 35 minutes. An approximately 0.5-mile walk to the fitness center served as their warm-up. They stretched as needed and initiated the exercise protocol. A warm-up load equal to 45–60 kg was placed on the barbell bench press, and they completed 8–10 repetitions. They were
provided a 2-minute recovery, and 70 (bench press and shoulder press) ~80% (leg press and lat row) of their predetermined IRM was placed on the bar. They completed 4 sets of as many repetitions as possible, with a 2-minute recovery provided between sets. A similar protocol was followed for the other 3 exercises, with the entire bout lasting approximately 1 hour. Number of repetitions per set and total weight lifted were used as an index of resistance training performance. Pilot work revealed a coefficient of variation for the number of repetitions completed over 4 sets equal to 7.0, 8.0, 7.2, and 6.9% for the 4 exercises, respectively. Consequently, a meaningful increase in performance was considered to be >72%, the mean of these values.

Subjects returned 1 week later and repeated the identical protocol after ingestion of the other treatment. After this trial, they filled out a survey containing questions regarding their health status, mood, onset of symptoms or side effects, and if they could identify the caffeine trial.

Assessment of Caffeine Concentration

Saliva samples (5–15 mL) were obtained immediately before capsule ingestion (time 0), at hour 1, 2, and 3 during the protocol and at least 8 hours after the treatment was ingested. They were not required to rinse their mouth before sampling, as they refrained from food intake for 3 hours pretrial and ingested only water during the course of the protocol. Subjects were instructed to spit into a 20-mL plastic cup, and the sample was then immediately transferred to a capped glass vial that was placed in a freezer until subsequent analysis.

Posttrial, subjects were informed not to ingest caffeine until the sample was then immediately transferred to a capped glass vial that was placed in a freezer until subsequent analysis. Saliva samples were defrosted at room temperature for about 1.5 hours.

One milliliter of the saliva sample was mixed with 1 ml of 0.1 M ammonium acetate buffer (pH = 4.6) and vortexed for 10 second. It was then loaded onto an SPE column (Phenomenex Strata X, 60 mg, 3-mL column volume, Torrance, CA, USA), which had been conditioned with 1 mL methanol and 1 mL of 0.1 M ammonium acetate buffer. The SPE column was washed with buffer (1 ml) and then methanol (1 mL) was used to elute the caffeine. The eluate was collected and concentrated under reduced pressure to dryness. Finally, the residue was dissolved in 100 μL of methanol and injected directly into the HPLC system for detection. Duplicate injections were made for each sample. Caffeine concentration for each sample (in microgram per milliliter) was reported as the average of the duplicate injections. The detection limit of the assay was equal to 10 μg·mL⁻¹.

A conventional chromatographic system was used, consisting of 2 constant-flow pumps (Shimadzu, Inc. Model LC-10 AT, Kyoto, Japan) coupled to a 5-μm C18 column (150 cm × 4.0 mm i.d.) through a high-pressure injection valve (Rheodyne Inc., Model RH-7725i, Cotati, CA, USA) with a 20-μL sample loop. The HPLC system was used together with a diode array detector (Shimadzu Inc., Model SPD-M10AVP). Caffeine concentration was detected at a wavelength of 270 nm. It was then loaded onto an SPE column (Phenomenex Strata X, 60 mg, 3-mL column volume, Torrance, CA, USA), which had been conditioned with 1 mL methanol and 1 mL of 0.1 M ammonium acetate buffer. The SPE column was washed with buffer (1 ml) and then methanol (1 mL) was used to elute the caffeine. The eluate was collected and concentrated under reduced pressure to dryness. Finally, the residue was dissolved in 100 μL of methanol and injected directly into the HPLC system for detection. Duplicate injections were made for each sample. Caffeine concentration for each sample (in microgram per milliliter) was reported as the average of the duplicate injections. The detection limit of the assay was equal to 10 μg·mL⁻¹.

Table 1. Salivary caffeine concentration in response to caffeine ingestion (6 mg·kg⁻¹) or placebo.*

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Caffeine (μg·mL⁻¹)</th>
<th>Range</th>
<th>Placebo (μg·mL⁻¹)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.80 ± 10.90</td>
<td>2.15–39.00</td>
<td>7.46 ± 10.20</td>
<td>0.99–36.70</td>
</tr>
<tr>
<td>1</td>
<td>30.50 ± 26.60</td>
<td>3.45–83.50</td>
<td>6.64 ± 8.52</td>
<td>0.39–30.50</td>
</tr>
<tr>
<td>2</td>
<td>27.90 ± 17.00</td>
<td>3.49–64.40</td>
<td>5.76 ± 9.42</td>
<td>0.27–30.50</td>
</tr>
<tr>
<td>3</td>
<td>41.80 ± 25.00</td>
<td>16.30–84.40</td>
<td>5.44 ± 6.28</td>
<td>1.03–22.80</td>
</tr>
<tr>
<td>+8</td>
<td>24.80 ± 16.40</td>
<td>8.29–106.20</td>
<td>4.87 ± 7.06</td>
<td>1.30–24.60</td>
</tr>
</tbody>
</table>

*Values are mean ± SD.
differences in salivary caffeine concentration. The Greenhouse–Geisser correction was used to account for the sphericity assumption of unequal variances across groups. For all dependent variables, Tukey’s post hoc test was used to identify differences between means when a significant $F$ ratio was obtained. The Pearson product moment correlation coefficient was used to identify relationships between salivary caffeine concentration and habitual caffeine intake and total weight lifted. Effect sizes were obtained for the following variables across treatment: repetitions completed (0.20) and total weight lifted (0.19). Statistical significance was established at $p \leq 0.05$.

**RESULTS**

Testing was well tolerated by all subjects. Only 4 of 14 (29%) subjects were able to correctly differentiate between the caffeine and placebo trial, because of feelings of “more energy,” “increased mood,” and “less fatigue.” Two participants reported feelings of nausea and anxiety during exercise in the caffeine trial.

**One Repetition Maximum Performance**

Mean ($\pm SD$) 1RM for the 4 exercises were equal to bench press (105.2 $\pm$ 5.2 kg), leg press (367.9 $\pm$ 19.0 kg), bilateral row (162.1 $\pm$ 6.1 kg), and shoulder press (77.1 $\pm$ 3.5 kg). These values validate subjects’ status as resistance-trained and place them in the 80th percentile for bench press and above the 90th percentile for leg press for young men (Institute for Aerobics Research, unpublished data, 1994).

**Determination of Caffeine Concentration**

Table 1 demonstrates changes in salivary caffeine concentration during the protocol. Caffeine concentration at 0 hours was similar ($p > 0.05$) across treatments. Because of loss of selected samples, caffeine concentration was obtained for only 12 subjects. Across all subjects, 6 revealed peak caffeine concentration at 1 hour, 4 at 2 hours, and 2 at 3 hours postingestion. In the caffeine treatment, mean peak caffeine concentration was equal to 43.50 $\pm$ 27.08 $\mu$g/mL$^{-1}$ (range = 11.3–83.5 $\mu$g/mL$^{-1}$). At each timepoint, salivary caffeine concentration varied. Data revealed a significant ($p < 0.05$) main effect of treatment on caffeine concentration, because it was consistently higher with caffeine vs. placebo. No main effect ($p = 0.33$) of time was revealed, although caffeine concentration gradually increased from baseline to 3 hours and decreased by 8 hours after ingestion. A nonsignificant interaction effect ($p = 0.13$) was revealed. There was no relationship ($p > 0.05$) between habitual caffeine intake and the salivary caffeine response, $r = -0.38$, $p = 0.23$.

**Resistance Training Performance**

The number of repetitions significantly decreased ($p < 0.01$) across all sets in all exercises with the exception of sets 3 and 4 for lat row exercise. There was a significant sets $\times$ treatment interaction ($p = 0.047$) for leg press repetitions but not for the bench press ($p = 0.79$), lat row ($p = 0.80$), or shoulder press ($p = 0.46$) with caffeine ingestion. These data are given in Table 2. Participants completed approximately 1.5 more repetitions in sets 1 and 2 of leg press with caffeine compared to placebo.

Total weight lifted was similar ($p > 0.05$) across treatment for the bench press (2,685.5 $\pm$ 154.7 kg vs. 2,573.8 $\pm$ 161.2 kg), leg press (13,943.4 $\pm$ 878.8 kg vs. 13,277.0 $\pm$ 1,005.8 kg), bilateral row (3,836.9 $\pm$ 258.0 kg vs. 3,698.1 $\pm$ 240.8 kg), and shoulder press (1,793.4 $\pm$ 165.7 kg vs. 1,679.7 $\pm$ 142.2 kg), respectively. However, 9 of 14 subjects lifted more total weight (>72%) in the caffeine trial vs. placebo.

**DISCUSSION**

Our results in resistance-trained men who were regular caffeine consumers showed a significant effect of acute caffeine ingestion on leg press performance, but the magnitude of this improvement was small and of little practical significance. Data demonstrated that upper-body performance was unaltered in response to caffeine intake, and total weight lifted was unaffected vs. placebo. Nevertheless, 9 of 14 subjects revealed meaningful increases in total weight lifted with caffeine ingestion, with 6 of these subjects maintaining a typical caffeine intake greater than 225 mg·d$^{-1}$. This improved performance occurred with reports of more...
energy' and 'enhanced mood.' Changes in salivary caffeine concentration were unrelated to performance. Overall, data do not support the ingestion of caffeine to enhance high-intensity resistance training, because the magnitude of this benefit was small and limited to strength-trained men with relatively high habitual intakes of caffeine. Additional research is needed to elucidate differences in performance gains in response to acute caffeine ingestion between individuals.

Recent studies do not support a caffeine-mediated effect on strength training performance, similar to this study. In strength-trained men, data (22) revealed no effect of a 4 mg·kg\(^{-1}\) caffeine dose on repetitions to fatigue at 70% (bench press) and 80% (leg press) 1RM vs. placebo. In men completing 1RM testing of the bench press and lat pull-down followed by repetitions to fatigue (40), 300 mg of caffeine did not alter any index of performance. No change in 1RM leg press or bench press was demonstrated in men consuming 6 mg·kg\(^{-1}\) caffeine (1). Data from Beck et al. (3) in active men revealed a 2.1% increase in 1RM bench press performance, yet caffeine was ingested as part of a supplement, and the physiological significance of this improvement (+2 kg) appears limited in this population. Recently, Sokmen et al. (34) stated that caffeine has little ergogenic benefit for repeated bouts of high-intensity exercise lasting between 15 seconds and 3 minutes that are reliant on nonoxidative metabolism, such as intense resistance training as completed in this study.

It has been suggested (13) that the ergogenic effect of caffeine may be greater in trained athletes compared to less-trained individuals. In elite cyclists (39), 5 mg·kg\(^{-1}\) of caffeine ingested 1 hour before exercise significantly increased 1-km time trial performance by 3% (71.1 ± 2.0 seconds) compared to placebo (73.4 ± 2.3 seconds). In elite rowers, data (5) revealed significantly faster time (−1.2%) to row 2,000 m after ingestion of 6 or 9 mg·kg\(^{-1}\) of caffeine vs. placebo. Sprint swim performance was significantly enhanced in trained but not recreational, swimmers after ingestion of 250 mg of caffeine (6). Woolf et al. (41) revealed enhanced bench press performance and peak power in elite male athletes. In male rugby players, 6 mg·kg\(^{-1}\) caffeine significantly augmented indices of high-intensity team sport performance including sprinting, force generation, and passing accuracy (36). In competition, these small improvements would dramatically affect athletes' performance, and perhaps separate winners from losers. Yet, the exact characteristic of trained muscle that fosters these adaptations is unknown. Additional investigation is warranted, both in the laboratory to compare alterations in performance with caffeine ingestion in trained and recreationally active individuals and in field-based studies examining performance changes during training, to further elucidate the ergogenic properties of caffeine in competitive athletes.

An explanation for the disparate results observed across studies is not because of inability to control participants' dietary and exercise status. In this study and others, a randomized, counterbalanced, double-blind crossover design was used, subjects refrained from vigorous exercise and caffeine intake for 48 hours before each trial, and they ingested the same foods in the 24 hours before each trial. This helps to ensure optimal performance (19). Previous studies (39,40,41) investigating the effects of caffeine ingestion on short-term performance used similar experimental controls but did not report caffeine concentration, as was done in this study and others (5,22). Our data (Table 1) showing a significantly higher \(p < 0.05\) caffeine concentration with treatment ingestion, and no change in salivary caffeine levels in the placebo trial, suggest that subjects abstained from caffeine intake pre-exercise as requested by our protocol.

A single mechanism to explain the ergogenic effects of caffeine has yet to be identified. Costill et al. (8) identified that glycogen sparing and enhanced lipolysis improved performance with caffeine during endurance exercise, although recent studies (14,15) have challenged this hypothesis. Caffeine has been shown to alter excitation–contraction coupling and calcium release at pharmacological doses (38), although these effects are unlikely at more physiological doses (30). Caffeine attenuates pain sensation (12,26) and RPE (10) during cycle ergometry, thereby decreasing perceptions of effort. It remains to be determined if such measures could be used during intermittent exercise such as resistance training, in which effort is typically maximal and subjects could not report their pain sensation during exercise because of the intense demands of the activity. Furthermore, caffeine directly stimulates the central nervous system through blocking of adenosine receptors (9), thus removing the inhibitory effects of adenosine on neuroexcitability (11) and arousal (28). These responses may explain caffeine’s ability to improve endurance performance (9), yet it is unknown if this effect occurs during high-intensity, intermittent exercise.

A novel result from the present study is that 66% (6 of 9) of subjects who revealed meaningful increases (+72%) in performance after caffeine administration were relatively heavy caffeine users, with daily intake greater than 225 mg. In contrast, the subjects who expressed reduced performance in the caffeine trial ingested less than 150 mg·d\(^{-1}\) of caffeine. It may be that in heavy caffeine users, withdrawal symptoms observed in the placebo trial, including headaches and lethargy, led to the reductions in performance compared to the caffeine treatment, in which these symptoms would be ameliorated. However, changes in salivary caffeine concentration from baseline to peak concentration were not related to the change in total weight lifted with caffeine, \(r = -0.13, p > 0.05\). Data from these men would suggest that the ergogenic effects of caffeine may be more dependent on changes in mood by reversing caffeine withdrawal (42) rather than altering force production, substrate provision, etc., although this is merely speculative and requires further study.
Caffeine and Resistance Training Performance

**Practical Applications**

Compared to placebo, caffeine provided a small improvement in performance in strength-trained men who were caffeine consumers. Number of leg press repetitions completed in sets 1 and 2 was significantly higher after ingestion of 6 mg·kg⁻¹ of caffeine, but there was no effect for upper-body exercise. Six of 9 men who revealed meaningful increases in total weight lifted with caffeine were relatively heavy caffeine users (>225 mg·d⁻¹), whereas, relatively low users (<150 mg·d⁻¹) tended to exhibit reduced performance. Any ergogenic benefit of caffeine for intense resistance training appears minimal and is most prevalent in heavy users of caffeine.

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**References**


